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10 Gbit/s OFDM based FSO communication system using M-QAM modulation with enhanced detection

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Abstract In this paper, we have presented analysis of 10 Gbit/s OFDM based FSO communication system using MQAM, under different weather condition and reported the improved performance by usage of a preamplifier and square root module (SQRT). A distance of 1800 m was achieved with the same performance as without SQRT representing an enhancement of 90 %.

Keywords Orthogonal frequency division multiplexing (OFDM) · Free space optics (FSO) · Quadrature amplitude modulation (QAM) · Square root module (SRM) · Line of Sight (LoS)

1 Introduction

Free space optics (FSO) communications is traditionally seen as being low cost with flexible deployment networking and dispense frequency licensing. Due to light dispersion, high weather conditions dependence and bandwidth restriction of electronic devices the data rate is often limited and performance is sometime seen as insufficient. High spectral efficiency and high ability to mitigate the atmospheric scattering effects can enhance the performance of data rate and bit error rate in FSO adoption of transmission technologies. Hence the combination of two mature technologies of orthogonal frequency division multiplexing (OFDM) and FSO can represent a viable solution. Maintaining a clear Line of Sight (LoS) between transmitter and receiver is essential for effective communication. But being free space, the atmospheric weather condition poses threat to this LoS, which is affected by fog, rain, snow, dust cloud and temporary obstruction like crossing of birds. Under various atmospheric conditions optical signal will suffer from absorption, scattering

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etc. (Awan et al. 2009, b). OFDM is used extensively in broadband wired and wireless communication systems [OFDM has been adopted in prominent wired and wireless broadband standards, including HDTV, DSL, IEEE 802.11 (WiFi) and 802.16(WiMAX) (Gonzalez et al. 2005; Cvijetic et al. 2006; Djordjevic 2007)]. This becomes increasingly important as data rates increase and quadrature amplitude modulation (QAM) is used, due to its reduced SNR. In OFDM, the received signal at any time depends on multiple transmitted symbols. In this case the complexity of equalization in serial schemes which use time domain equalization rises rapidly (Bahai and Saltzberg 1999). OFDM presents an alternative for improving FSO transmission. Due to its high spectral and power efficiency and simple Frequency-domain equalization, optical OFDM has been demonstrated for free space links (Jansen 2007). Experimental demonstration of 10 Gbit/s free-space optical transmission using OFDM have been reported in Cvijetic and Qian (2007). In-field experiment of OFDM over free-space optical channels at a rate of 300 Mbps over a range of 1.87 km is presented in Mostafa and Hranilovic (2012).

In this work, we presented simulation investigation of 10 Gbit/s OFDM based FSO communication system using M-Ary QAM modulation. The simulation setup is reported in Sect. 2 followed by the simulation results discussion in Sect. 3. The conclusion is drawn in Sect. 4.

2 System description

In our proposed optical OFDM system (Fig. 1), 10 Gbit/s QAM data is generated and then modulated into OFDM by means of OFDM modulator using 512 subcarriers, position array of 256, FFT size of 1024 and cyclic prefix of zero value. These are then IQ modulated at an intermediate frequency of 7.5 GHz. This Intermediate signal modulates directly the light of a continuous wave (CW) through a MZM. The light is then adapted to the free space optical (FSO) propagation by collimators. The attenuation of the air is changed from 0 or

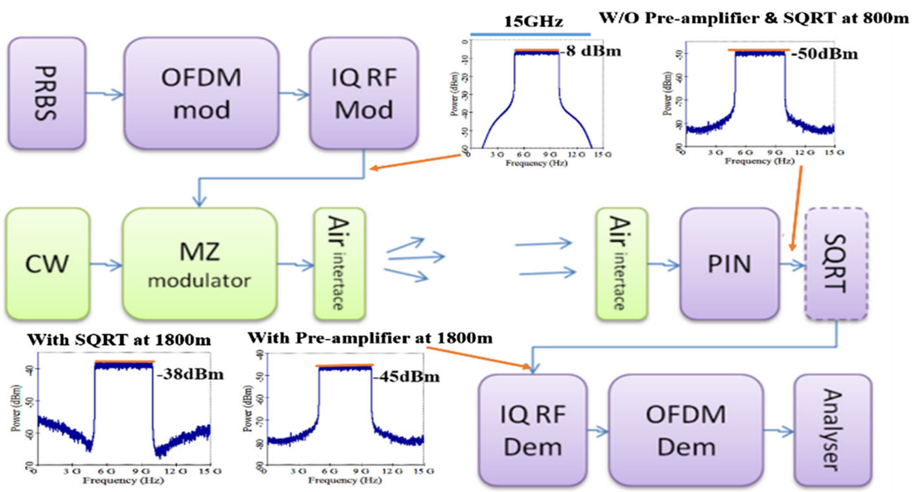

Fig. 1 Simulation setup of optical OFDM based FSO system

200 dB/km depending on the weather conditions. After propagation the signal is again collimated to a PIN photodiode (Fig. 2).

Besides the test of the SQRT impact on the system several other performance factors were observed: beam divergence, receiver aperture, transmitter power and weather conditions. In the following sections the results will be detailed (Fig. 3).

3 Results and discussion

For the sake of reference performance and better understanding of the benefits of the proposed scheme, we have started by characterizing the system without the SQRT module under several conditions and then considering the SQRT module.

3.1 Analysis of 10 Gbit/s OFDM based FSO communication system using QPSK modulation

The parameters used in this case are transmission length is set to 1800 m, Line width 5 MHz and transmitter aperture diameter 10 cm.

Figure 4a–c depict the evaluations of the SNR versus free space transmission range with different conditions. From Fig. 4a, it is observed that distance for an SNR $\sim$ 15 dB is reduced from 1800 m to less than 500 m when the beam divergence is increased from 0.25 to 1.5 mrad showing as expected, the high impact of the beam divergence on the reach. Moreover, for a fixed beam divergence back to 0.25 mrad, Fig. 4b shows that the receiver aperture changing from 30 to 10 cm also reduces greatly the range, from more than 1800 to less than 1000 m. Figure 4c shows that the transmitter power changing from 40 to 5 mW also reduces greatly the range, from more than 1800 to less than 600 m.

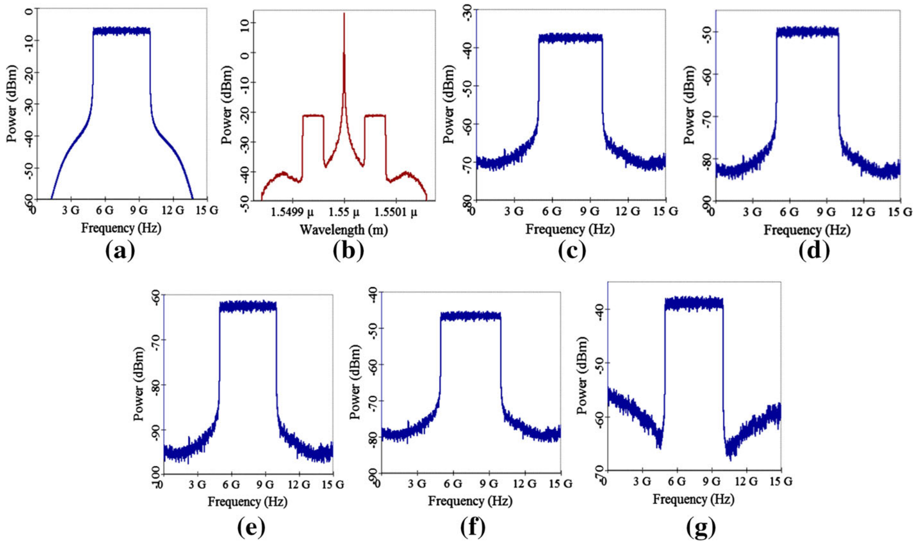

Fig. 2 Electrical spectrum of Optical OFDM signal at various points: **a** before the MZM, **b** optical spectrum after MZM, **c** after the PIN at B2B, **d** after the PIN without preamplifier at 800 m, **e** after the PIN with preamplifier at B2B, **f** after the PIN with preamplifier at 1800 m, **g** after the SQRT module (when present)

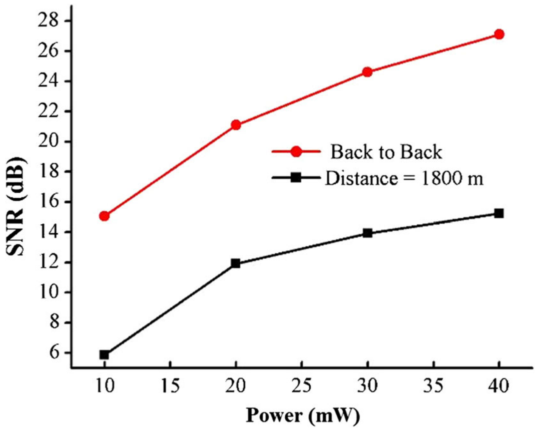

Fig. 3 Evaluation of SNR (dB) versus power with B2B and 1800 m

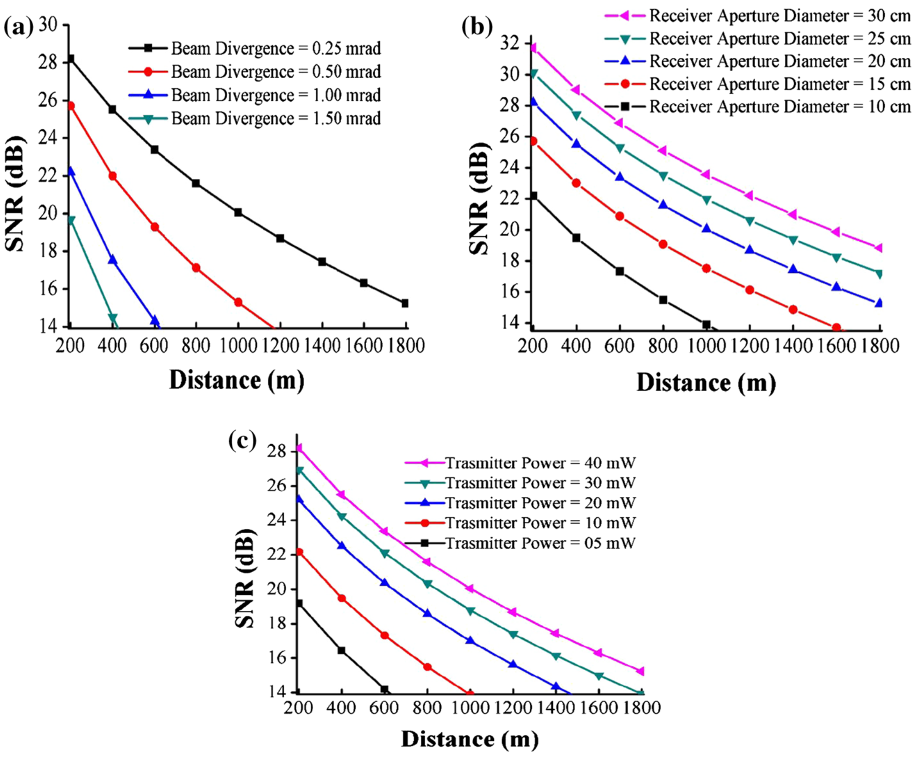

Fig. 4 Evaluation of SNR (dB) versus distance with: **a** Beam divergence, **b** receiver aperture diameter, **c** trasmitter power

In order to test the attenuation impact on the performance of such a system, different weather conditions as shown in Table 1 are considered and tested. Please consider the maximum attenuation of the each of the ranges.

Table 1 Parameter of different weather condition (http://www.weizmann.ac.il/conferences/frisno8/presentations05/thursday/medved.pdf)

Weather condition	Attenuation (dB/km)
Clear weather, light haze	0–3
Light rain	3–6
Heavy rain	6–17
Snow	10–35
Light fog	17–70
Heavy fog	80–200

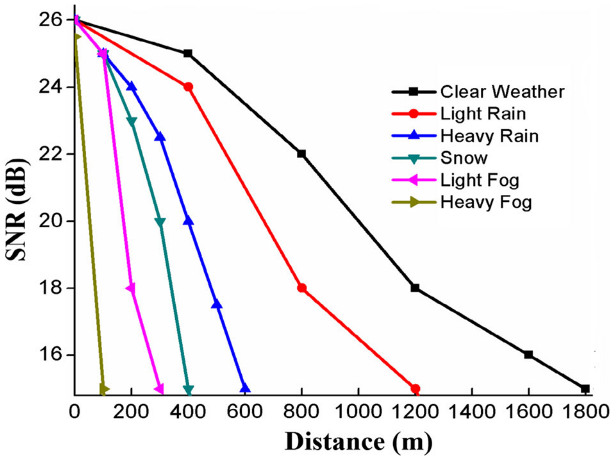

Fig. 5 Evaluation of SNR (dB) versus range with different weather conditions

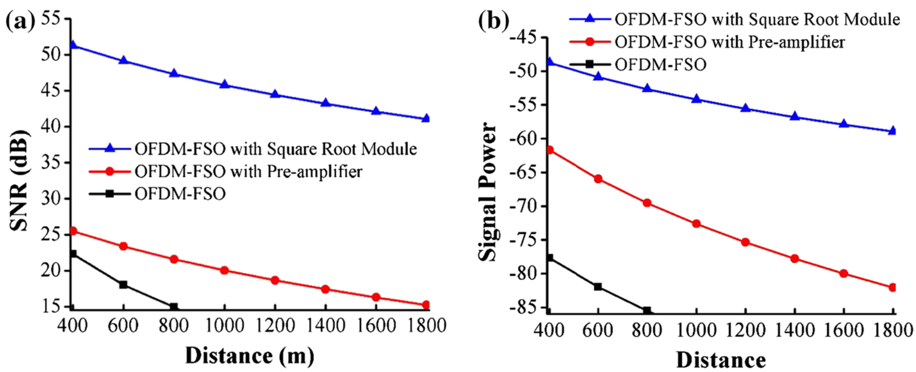

Fig. 6 **a** Evaluation of SNR versus distance without, with Pre-amplifier and SQRT module, **b** evaluation of signal power versus distance without, with Pre-amplifier and SR module

Figure 5 depicts the results of the SNR as a function of the transmission range at different weather conditions. The change of weather from clean weather to heavy fog may limit range from the 1800 m down to 80 m.

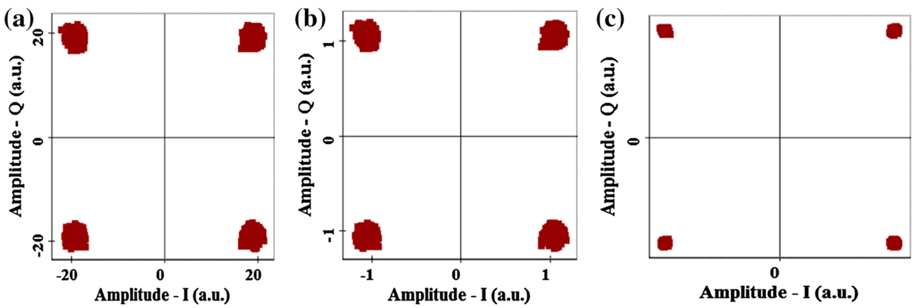

Fig. 7 Constellation diagram of 4QAM-OFDM-FSO system after **a** B2B with Preamplifier, **b** 1800 m with Preamplifier and **c** with SQRT module

3.2 Improved performance of the 10 Gbit/s OFDM based FSO communication system

In this next analysis we will consider the SQRT module following the PIN to compensate for its square law response (Prat et al. 2006) resulting in improved performance of the linear equalizer (Sharma and Kumar 2013; Prat et al. 2005; Kumar et al. 2014).

Figure 6a, b depicts the measurement of SNR and signal power versus transmission distance with & without preamplifier and SQRT module. It can be observed the improvement stemming from the usage of the preamplifier and SQRT module. The SNR is improved in B2B by 25 dB and the reach greatly extended above the 1800 m.

For better insight we also show in Fig. 7 the three 7.5 GHz QPSK constellations at (a) B2B; (b) with Preamplifier; (c) with SQRT.

4 Conclusion

In this work, we have analyzed a 10 Gbit/s OFDM based FSO communication system using 4QAM modulation with and without preamplifier and SQRT module. The results under different conditions show the typical limitations of these systems for the various parameters of the FSO system (beam divergence, receiver aperture, transmitter power, weather conditions). It is evidenced that these parameters greatly influence the results reducing for the considered parameters the propagation from the 1800 m of B2B. It is then shown that the introduction of a pre-amplifier and SQRT module, greatly improves the performance of the system alleging the system a B2B higher SNR margin and a much extended reach is predicted.

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